Microhole Drilling and Instrumentation Technology

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For the past five years, the EES Drilling Team, in collaboration with major oil companies and oil-field service providers, has been involved in developing a subsurface exploration capability, termed microhole drilling and instrumentation technology, which promises a very substantial reduction in exploration and development costs. Simple in concept, microhole technology reduces drilled-hole size to the smallest size that is still compatible with good drilling practice and permits the continued access by instruments for subsurface measurements. Figure 1 illustrates microhole diameters relative to conventional oil and gas exploration and production well sizes.

Microholes have from 1/25th to 1/50th of the cross-sectional area of conventional wells. By reducing the terminal-depth hole diameter to sizes in the range of 1 to 2 inches, we expect to substantially reduce the cost of all deep subsurface exploration and characterization. As an example, Figure 2 shows the relative costs of conventional and microhole technologies for a coal-bed methane exploration-and-development project that has been proposed for remote Alaskan villages. The project would supply coal-bed methane for heat and electricity in villages now dependent on diesel-fueled generators for power. Savings in drilling costs result from the smaller drill sites, much smaller draw-works for pipe and tube handling, greatly reduced material for drilling and well completion, and fewer support personnel.

Los Alamos is particularly well qualified to undertake the development of microhole technologies. Over the past 25 years, EES Division and its predecessors have participated in programs contributing to U.S. efforts in geothermal-, oil-, and gas-resource development. As a consequence of these programs, we have acquired extensive exposure to well drilling and completion, well logging technology, and borehole seismic-instrumentation development. Our team's familiarity with well technology has been essential

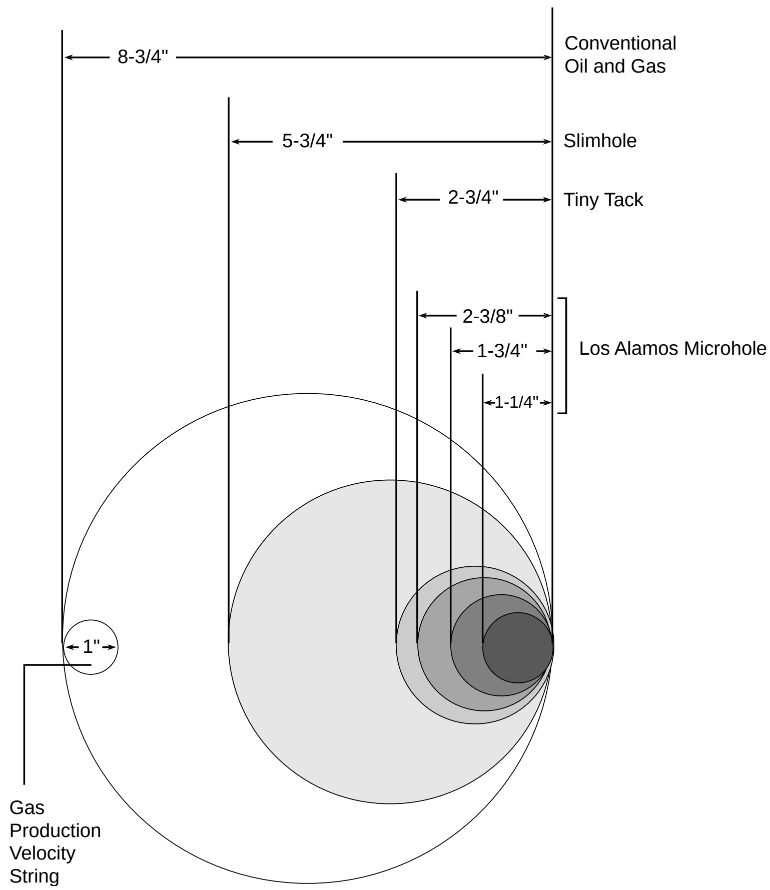

Figure 1. Relative Dimensions of Conventional Wells and Microholes. Our team currently drills microholes 1-3/4″ and 2-3/8″ in diameter with the ultimate goal of drilling deep microholes 1-1/4″ in diameter.

for undertaking a project with the scope and complexity of microhole technology development. Engineering efforts associated with this project encompass evaluating the feasibility of drilling deep microholes; integrating microhole drilling subsystems; field testing bottomhole, coiled-tubing drilling assemblies; miniaturizing geophysical logging tools; and incorporating emerging miniature sensor technologies in borehole seismic-instrumentation packages.

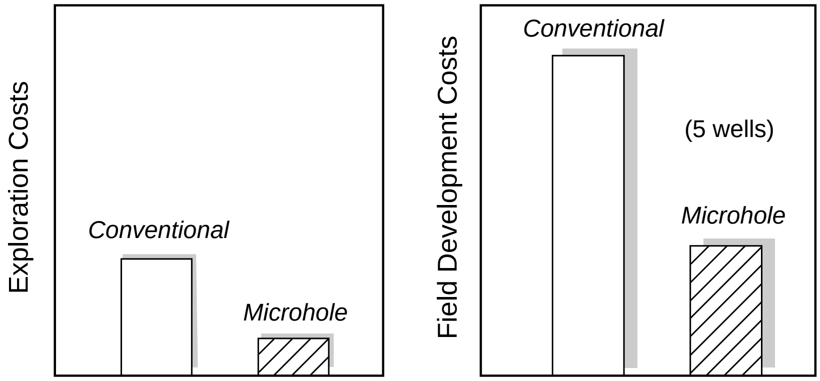

Figure 2. Relative Costs.
The figure illustrates the relative costs of conventional wells and microholes for coal-bed methane exploration and field development in remote Alaska based on cost data for conventional wells obtained by the Division of Geological and Geophysical Surveys of the Alaskan Department of Natural Resources.

Los Alamos Microhole Drilling System

The Los Alamos microhole drilling system, which corresponds in many respects to much larger sized commercial rigs, consists of a mechanical rotary drag bit, a hydraulically powered positive displacement motor, and a coiled-tubing drill stem. This hardware, termed a bottomhole assembly, is deployed for drilling using the coiled-tubing unit that is shown in Figure 3, along with its mud-conditioning and cementing equipment. For the initial tests, we either procured or fabricated components suitable for drilling 1-3/4 in. microholes and then tested them as a bottomhole assembly in an industrial laboratory. Laboratory tests for motor and bit performance demonstrated that these assemblies were suitable for coiled-tubing-supported drilling. Penetration rates in Berea sandstone and Carthage marble exceeded 100 ft/h.

Currently, we are drilling and casing 2-3/8 in.-diameter microholes to depths of 600 ft with the equipment shown. The drilling has been in basin-and-range valley fill and volcanic tuff. In the five wells drilled to date, we have encountered no problems that we would not expect to see in conventional drilling, and the problems were successfully addressed with conventional methods. As microholes are drilled deeper, we expect that conventional methods will have to be modified, if not replaced with advanced technology.

Logging Tools and Borehole Instrumentation

We have begun designing and fabricating a basic suite of 7/8 in.-diameter logging tools that will include both spectral-gamma and electrical-resistivity tools. It will also include a capability for surveying the trajectory of completed microholes. Furthest along in development is the gamma tool, which will be used to measure the natural radioactivity of rock penetrated by microholes.

Microhole Gamma Tool. The radiation incident on a sensor deployed in a microhole will always be greater than that for a conventional tool in a cased 8-1/4 in. hole. Figure 4 demonstrates this with an approximate calculation for the relative gamma radiation incident at three different energies on gamma-ray detectors packaged in cylindrical 7/8 in.-diameter and 3-1/4 in.-diameter stainless steel logging-tool housings.

In the foregoing calculation, we take into account only the absorption of gamma rays propagating perpendicular to the borehole. Off-normal flux components will also be greater for the microhole tool because of the closer proximity of the rock above and below the sensor in a microhole. The increased gamma flux incident

Figure 3. Drilling Systems.
The microhole drill rig (upper right), mud system (upper left), and batch cement mixer (lower left) at a field site in central Nevada are being used to drill microholes for emplacement of seismic-instrumentation packages.

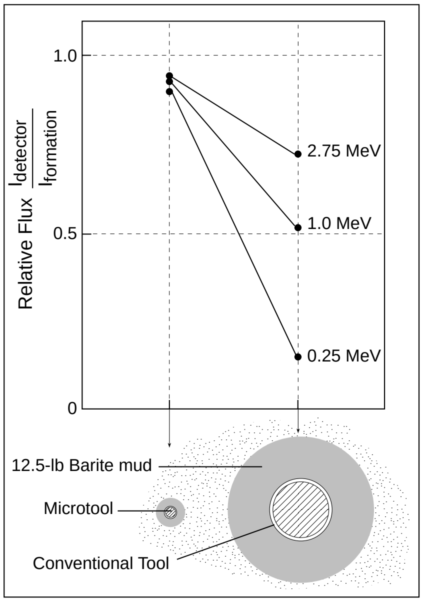

Figure 4. Relative Flux.
The figure shows the calculated relative gamma flux incident (left) on a 7/8 in. diameter sensor package in a 1-3/8 in. microhole and (right) on a commercial 3-3/8 in. logging tool in an 8-1/4 in. production well. Both tools are in open boreholes filled with barite mud.

on the microhole tool, however, is offset by the reduced photopeak-detector efficiency inherent in its smaller sensor.

Theory dealing with the gamma-capture efficiency of NaI crystals—the material most commonly used for gamma-ray detection in borehole logging tools—has yet to deal effectively with cylinders of the high aspect ratios found in logging tools. Consequently, a calculation of their relative photopeak efficiency was not practical. To address this question, we designed and fabricated a microhole gamma tool to compare its efficiency directly with that of a conventional tool. Making this comparison early in the microtool design effort is important if we are to determine the relative counting time for the two tools in a constant gamma flux. If the microtool's counting time is excessively long compared with that of the commercial tool, we will have to increase the mass of the NaI crystal in the final microtool design.

Figure 5 compares counts registered on a microtool detector assembly with those of a commercial logging tool over the energy range of 100 to 2,000 keV. In this case, there is no absorbing medium between a bismuth-207 point source and the respective tool housings; the measurement is done in air. The results show that the photopeak efficiency of the microtool NaI crystal is greater than 0.4 times that of the commercial tool, reaching up to roughly 1,200 keV and then decreasing rapidly.

We designed a test setup to compare the overall performance of the microtool with that of a commercial tool, while taking into account the competing effects of increased flux and reduced photopeak efficiency, over a range of borehole diameters, casings, and fluids. The test setup consists of a potash-filled barrel in which various combinations of casing and gamma tools can be easily inserted for spectral gamma measurements. Once the comparative measurements are completed, we will be able to determine the crystal mass required for the microhole tool's performance to match that of the commercial tool.

Microhole Resistivity Tool. The Cedar Bluff Group, a company specializing in formation resistivity measurements for the oil industry, recently completed a comprehensive review of all types of resistivity/conductivity tools and the relative merits of their use in microholes for EES Division. They reviewed data on focused and unfocused electrodes and low- and high-frequency induction logging tools.

Cedar Bluff identified the special constraints imposed on tool design by the 7/8 in.-diameter limitation and analyzed the constraints, along with estimating the performance limitations of the various types of tools. They found that, although electrode tools are less affected by diameter, they still present some significant mechanical design challenges. Cedar Bluff also reviewed the environmental factors affecting performance, comparing the relative effects on conventional and microhole resistivity logging of the following: drilling muds, casing, post-completion borehole fluids, invasion, and rocks possessing conductivity extremes.

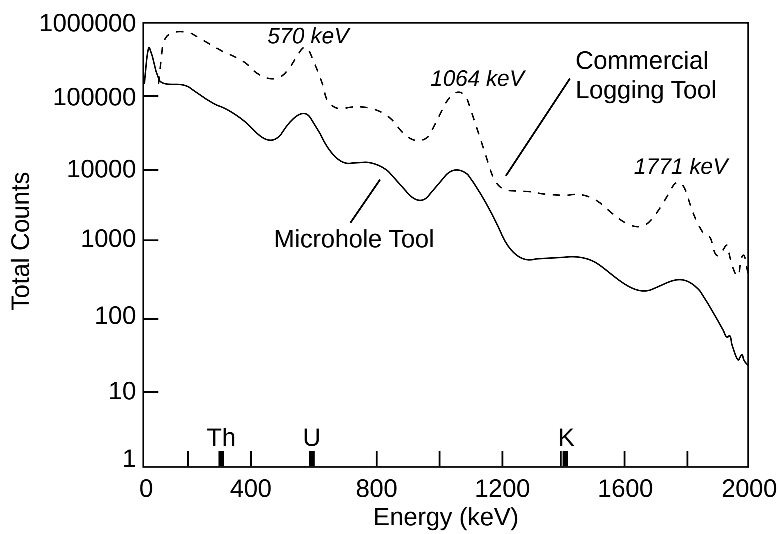

Figure 5. Count Comparison.
The figure compares total counts for 1-11/16 in. commercial and 7/8 in.-diameter microhole gamma tools using a point bismuth-207 source. The source is located 4 in. from the center of a NaI crystal in each tool. The length and radius of the crystals are 6 x 1 in. and 4 x 1/2 in., respectively.

The small available cross-sectional area in a microtool compels us to use the higher-frequency induction tools to compensate for the reduced sensitivity of the small transmitting and receiving coils. High-frequency tools provide a higher resolution than current commercial logging tools in conventional-size wells. The Cedar Bluff Group has recommended the development of a high-frequency induction tool consistent with current state-of-the-art design in microhole logging tools.

Microhole Seismic Array Design, Fabrication, and Testing

Our team, capitalizing on Input/Output, Inc. (IOC) in-house microelectromechanical systems (MEMS) accelerometer technology, designed, fabricated, and tested two four-level, three-component seismic arrays, which were based on a successful prototype. To the best of our knowledge, this is the first reported use of the MEMS technology for a borehole seismic array.

We substantially redesigned the prototype 7/8 in.-diameter borehole package, which provides initial information on the performance of the MEMS sensor, to serve as an interchangeable sensor pod in a multipod-array system. In collaboration with Phillips Petroleum, we then deployed the arrays to (1) demonstrate that successful deployment in and retrieval from microholes was possible, and (2) evaluate the potential contribution that data from microhole arrays could make to seismic-reflection surveying.

With respect to our first objective, four 2-1/4 in.-diameter microholes were drilled to depths of between 300 and 500 ft using the Los Alamos coiled-tubing drilling unit. These wells were cased by grouting in 1-1/4 in.-inside-diameter flush-joint PVC tubing. A subcontractor to Phillips Petroleum collected two-dimensional reflection data simultaneously from conventional surface geophone arrays and from the two MEMS microhole arrays using IOC's System-2 data-acquisition equipment. The arrays were successfully deployed and retrieved without incident.

So far, borehole field data results indicate comparable sensitivity; however, these data also indicate a lower signal-to-noise ratio than that of nine-geophone gathers used in a reflection line. Array noise levels gradually declined with the depth of each array pod, and the horizontal array elements recording the elastic waves showed lower amplitude motion than did the verticals.

Conclusions

At this stage in our study of microhole technology, we have not found any fundamental technical barriers either to the drilling of deep microholes or to their instrumentation for a variety of applications. Rather, microhole technology appears to offer the prospect of improved subsurface measurements at greatly reduced cost. ■

Further Reading

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